SEARCH FOR SM AND MSSM HIGGS BOSONS AT LEP*

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Latest results from the LEP Collaboration on searches for neutral Higgs bosons predicted by the Standard Model and its minimal supersymmetric extension, the MSSM, are summarized.

1. Introduction

The four LEP experiments (ALEPH, DELPHI, L3 and OPAL) collected around 2.5 fb^{-1} data in total at energies $\sqrt{s} \geq 189$ GeV of which 536 pb^{-1} was registered at $\sqrt{s} = 206 - 209$ GeV in 2000. The data are used to search for Higgs bosons in a variety of models.

In the Standard Model (SM) the electroweak (EW) symmetry is broken via the Higgs mechanism generating the masses of elementary particles. This implies the existence of a single neutral scalar particle, the Higgs boson. While the SM is successful in describing the observed phenomena there are several theoretical arguments requiring its extension. The minimal supersymmetric (SUSY) extension of the SM (MSSM) introduces two Higgs field doublets leading to five Higgs bosons: three neutral and two charged.

2. Standard Model

At LEP energies, the SM Higgs boson is produced via the Higgs-strahlung process $e^+e^- \rightarrow HZ$. Vector-boson fusion processes $e^+e^- \rightarrow He^+e^-$ and $H\nu_e\bar{\nu}_e$ play also some role close to the kinematic limit. The Higgs boson is expected to decay predominantly into $b\bar{b}$ with some contribution to $\tau^+\tau^-$, gg, W^*W^* and $c\bar{c}$. For a Higgs mass of 115 GeV, more than half of the Higgs events are expected in the four-jet channel (HZ $\rightarrow b\bar{b}q\bar{q}$).

During the last year of LEP operation the ALEPH collaboration observed an excess of four-jet events compatible with SM Higgs boson production with a Higgs mass of 115 GeV. For this mass hypothesis, the ALEPH data give a background confidence $1-\text{CL}_\text{b} = 3.3\times10^{-3}$, corresponding to an approximately 3σ excess, and a signal-plus-background confidence $\text{CL}_{\text{s}+b} = 0.87$. When combined with the results of the other LEP experiments[1] the significance of the excess decreases below 2σ, and the confidences are $1-\text{CL}_\text{b} = 0.09$ (see Figure 1 (a)) and $\text{CL}_{\text{s}+b} = 0.15$. A lower bound of 114.4 GeV is set on the mass of the SM Higgs boson at the 95% CL with an expected limit of 115.3 GeV as shown on Figure 1 (b). The data are also used to derive limits on the HZZ coupling for various assumptions concerning the Higgs boson decay properties (see Figure 1 (c) for the assumption of 100% H $\rightarrow$ b$\bar{\text{b}}$ decay).
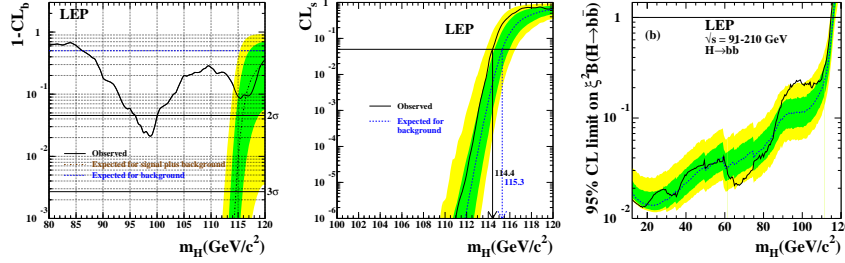

Figure 1. Search for the SM Higgs boson. (a) The background confidence 1-CL$_\text{b}$. (b) The ratio $\text{CL}_\text{s}=\text{CL}_{\text{s}+b}/\text{CL}_\text{b}$ for the signal-plus-background hypothesis. (c) The 95% CL upper bound on the coupling ratio squared $\xi^2 = (g_{\text{H}ZZ}/g_{\text{H}ZZ}^{SM})^2$ assuming that the Higgs boson decays exclusively into b$\bar{\text{b}}$.

3. MSSM

In the MSSM, the Higgs potential is assumed to be invariant under CP transformation at tree level. It is possible, however, to break CP symmetry in the Higgs sector by radiative corrections. Such a scenario provides a possible solution to the cosmic baryon asymmetry.

Both CP conserving (CPC) and CP violating (CPV) scenarios are studied at LEP. In the CPC case, the three neutral Higgs bosons are CP eigenstates: h and H are CP even, A is CP odd. They are mainly produced in the Higgs-strahlung processes $e^+e^- \rightarrow$ hZ and HZ and the pair-production processes $e^+e^- \rightarrow$ hA and HA. In the CPV case, however, the three neutral Higgs bosons, H_i, are mixtures of CP-even and CP-odd Higgs fields and the $e^+e^- \rightarrow H_iZ$ and H_iH_j $(i,j = 1,2,3, i \neq j)$ processes may all occur. The decay properties of the Higgs bosons, while quantitatively different in the

two scenarios, maintain a certain similarity: the largest branching ratios are those to $b\bar{b}$ and $\tau^+\tau^-$ and cascade decays ($h \rightarrow AA$ and $H_2 \rightarrow H_1 H_1$) occur and can even be dominant when kinematically allowed.

A large number of search channels are used in the MSSM Higgs hunt: SM Higgs searches are reinterpreted, searches for hA pair-production, bbh and bbA Yukawa productions, flavour independent hZ and hA, decay mode independent hZ searches are developed. $h \rightarrow AA$ and $A \rightarrow hZ$ decays are considered in cascade decays leading to six-fermion final states. The search for invisible decay of Higgs bosons is also useful to explore specific areas of the MSSM parameter space. In general, searches designed to detect CPC Higgs production can be reinterpreted in the CPV scenario. However, in some parts of the CPV parameter space modified or newly developed searches are also necessary to cover new final state topologies.

The results of the different Higgs searches are interpreted in the framework of a constrained MSSM with seven parameters. At tree level two parameters are sufficient to describe the Higgs sector, they are chosen to be the ratio of the vacuum expectation values ($\tan\beta$) and a Higgs mass (m_A in CPC and $m_{H^\pm}$ in CPV scenarios). Additional parameters appear after the radiative corrections: the soft SUSY breaking parameter in the sfermion sector at the EW scale (m_{SUSY}), the SU(2) gaugino mass parameter (M_2), the common trilinear Higgs-squark coupling parameter (A), the gluino mass ($m_{\tilde{g}}$) and the SUSY Higgs mass parameter (μ).

Instead of varying all the above parameters, only a certain number of representative benchmark sets are considered where the tree level parameters are scanned while all other parameters are fixed. On top of the traditional three LEP benchmark scenarios (large-μ, no-mixing and m_h-max) several new scenarios, motivated by limits from $b \rightarrow s\gamma$ and $(g-2)_\mu$ measurements or by future searches to be conducted at the LHC, are studied. The recently proposed CPV scenario, called CPX, and its several derivates are also probed.

The large-μ scenario, designed to be kinematically always accessible but to have the $h \rightarrow b\bar{b}$ decay suppressed, is entirely excluded by the preliminary LEP combination[2] thanks to flavour independent searches. The no-mixing scenario where the parameters are arranged to have no mixing between the left- and right-handed stop fields, is strongly constrained even by a single experiment[3,4] as shown in Figure 2. In the m_h-max scenario which gives the maximal value of m_h for given $\tan\beta$ and m_A, the lower limit on the Higgs boson masses are $m_h > 91.0$ GeV and $m_A > 91.9$ GeV and the range $0.5 < \tan\beta < 2.4$ is excluded[2]. Studies from the OPAL experiment show that

the newly proposed CPC benchmark scans do not present new difficulties at LEP: the derived lower limits on the Higgs boson masses[5] in the new benchmark scenarios vary between 79.0 and 84.5 GeV for h and 84.0 and 90.0 GeV for A.
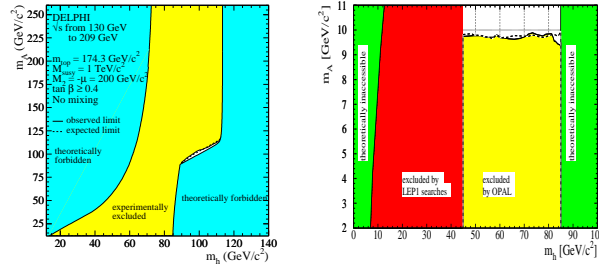

Figure 2. Search for the MSSM Higgs boson, no-mixing scenario. Exclusion in the m_h – m_A plane (a) by the DELPHI collaboration using traditional hZ and hA searches and (b) by the OPAL collaboration using a dedicated search for hZ $\rightarrow$ AAZ for low m_A.

The CPX scenario with maximal CP violation in the Higgs sector shows a decoupling of H_1 from the Z in the range $4 < \tan\beta < 10$. H_2 couples to the Z and heavier than around 100 GeV. Where kinematically open $H_2 \rightarrow H_1 H_1$ is dominant. The excluded areas[5] are shown in Figure 3.
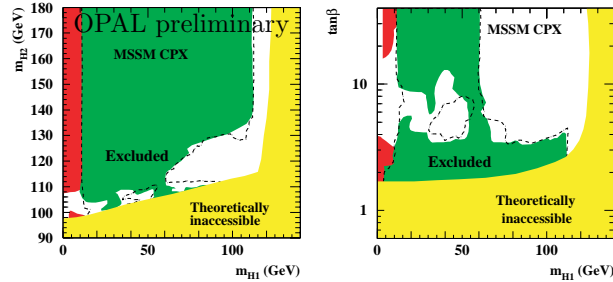

Figure 3. Search for the MSSM Higgs boson, CPX scenario. Exclusion in the (a) m_{H_1} – m_{H_2} and (b) m_{H_1} – $\tan\beta$ planes.

References

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